PEDESTRIAN COMPLIANCE EFFECTS ON SIGNAL DELAY

by Mark R. Virkler

The ability to accurately predict pedestrian delay at signalized intersections is central in evaluating the quality of flow in downtown or other high density areas. Pedestrian signal delay is usually modeled by assuming that pedestrians arrive at the signal randomly throughout the cycle and proceed only when a WALK signal is given to provide the right of way. There are times when some pedestrians will ignore the indicated pedestrian signal to minimize their own delay. This research was aimed at describing the range of delay reductions that pedestrians achieve by violating the indicated pedestrian signal. The results should prove useful for considering pedestrian delay when timing traffic signals and in describing the quality of flow experienced by pedestrians in signalized street networks.

Background information is given in the next section, followed by a description of a study conducted to quantify pedestrian compliance with traffic signals and delay savings in a central business district area. Recommendations to improve the prediction of pedestrian delay are then presented.

BACKGROUND

There are three pedestrian indications normally encountered:

1. WALK - the time period when pedestrians are expected to leave the curb, equivalent to a green signal for a vehicle. This time will normally be no shorter than several seconds but may be much longer. Here it is also referred to as “pedestrian green” or “green”.

2. Flashing DON’T WALK - the clearance time for pedestrians equal to the crossing length divided by the expected walking speed (normally 1.2 m/s). This period is often viewed as equivalent to a clearance interval for a vehicle (an all red phase), but it is much longer due to the pedestrian’s lower speed. The length to be crossed is often given as the pavement width to reach a pedestrian refuge island or the pavement width minus one-half of the width of the last lane to be crossed. An implicit assumption is that a pedestrian in the middle of the last lane when the period ends clearly has the right of way over a vehicle which is just receiving a green signal. Here it is also referred to as “pedestrian clearance” or “clearance”.

3. Solid DON’T WALK - the time period during which the pedestrian is not to have the right of way as assigned by the signal. Here it is also referred to as “pedestrian red” or “red”.

A logical model of pedestrian delay might assume all pedestrians who arrive during the pedestrian clearance and the pedestrian red will wait until the beginning of the pedestrian green interval and then immediately enter the crosswalk. Braun and Roddin *(1)* gave the following equation, based upon random arrivals, constant cycle length, no pedestrian actuation, and complete signal compliance.

$$D = \frac{(R + A)^2}{2C} = \frac{(C - G)^2}{2C} \qquad \text{(Eq. 1)}$$

where: D = average delay per pedestrian
R = duration of red or DON'T WALK signal
A = duration of clearance or flashing DON'T WALK signal
C = cycle length
G = duration of WALK signal

This equation differs from well known delay equations for vehicles that might use the same signalized intersection, such as Webster's formulation *(2),* in two major ways. First, it assumes that all pedestrians leave a stationary queued state instantaneously when the green signal is given. Vehicles are often assumed to incur a start-up delay of about two seconds and then proceed at roughly a two second headway in each lane. Ten queued vehicles in a lane would therefore require about 22 seconds of vehicular green time to enter an intersection during a given green phase. On the other hand, ten pedestrians could enter a crosswalk in a much shorter period of time. The queue discharge capacity of a 3 m wide pedestrian crosswalk is about 240 pedestrians per minute (or about 4.2 pedestrians per second) compared to about 30 vehicles per minute (or 0.5 vehicles per second) in a vehicle lane of similar width *(3,4).* For this reason, ignoring pedestrian start-up delay and saturation flow rate is normally a less severe problem than ignoring the same parameters for autos.

The second major difference in modeling pedestrian delay is that auto drivers often encounter overflow delay. Particularly during peak periods, not all queued vehicles will clear the intersection on the first vehicular green indication. Rather, some may have to wait for more than one signal cycle. In the author's experience, pedestrians almost never experience overflow delay but, rather, can generally enter the intersection on the first green signal.

A third major difference is that some pedestrians are likely to not obey the traffic signal. Equation 1 assumes complete compliance. Braun and Roddin (1978) suggested that Equation 1 could be modified, as shown below.

$$D = \frac{F(R + A)^2}{2C} \qquad \text{(Eq. 2)}$$

where: F = fraction of pedestrians who obey signal

In this formulation non-complying pedestrians are assumed to receive no delay.

An accurate model of pedestrian delay could significantly affect how pedestrian needs are addressed. When delay became the Highway Capacity Manual's (*3*) indicator of level of service for motor vehicles at signalized intersections in 1985, traffic engineers responded by increasing efforts to improve level of service by reducing delay. If one accepts the premise that delay is an important indicator of quality of flow for pedestrians, then it is appropriate to reduce delay. A reliable model of delay would appear to be a prerequisite in this effort.

Non-compliance with traffic signals affects pedestrian delay. The field study described below sheds more light on the behavior and the delay implications of pedestrians who do not obey the traffic signal.

FIELD STUDY

Data were collected in the central business district area of Brisbane, Australia at 18 crosswalks, involving 36 crosswalk directions. The sites were selected to represent important pedestrian routes. Most of the people using the intersections seemed to be typical of walkers in CBDs. The signals were all part of the city center coordinated signal grid.

Data were collected in 15 minute increments. Some of the crosswalks were examined for than one 15 minute increment to represent more than one time of day, leading to a total of 50 observations of 15 minutes duration. The time periods for data collection were between 9:00 a.m. and 1:00 p.m. on Wednesdays and 1:30 to 5:30 on Fridays. The data collected were:

1. The number of pedestrians who cross with the green signal (referred to as "complying")
2. The number of pedestrians who enter the crosswalk during the clearance interval (referred to as "runners" since many increased their speed while still on the sidewalk approaching the crosswalk when they saw that they would soon miss the chance to cross unless they increased their speed)
3. The number of pedestrians who enter the crosswalk during with the red interval (referred to here as "jumpers" because, in many cases, they have waited at the crossing until an adequate gap has appeared in the vehicular traffic into which they can "jump ahead" of the WALK signal.)
4. The delay of all pedestrians using that crosswalk direction.

For runners, the number of seconds left in the clearance interval for the last runner was recorded. For jumpers, the number of seconds between the first jumper and the beginning of green was recorded. The volumes and times were recorded on a cycle by cycle basis with the data then aggregated into 15 minute intervals.

One observer recorded the above volumes and times while a second observer recorded the number of pedestrians stopped and waiting to cross at short intervals (e.g., every 15 seconds). Using a standard stopped delay measurement technique often used in vehicle studies *(3)*, when the interval was t seconds, each person stopped represented t person seconds of delay. The total person-seconds of delay during a 15 minute period was then divided by the pedestrian volume during the 15 minutes to estimate the average stopped delay per person during that 15 minute period.

Data

As shown in Table 1, the intersections had volumes and signal cycle parameters typical of many cities.
Signal compliance ranged from 33.3% to 97.4%. One location with a volume of only 38 pedestrians had no runners. Otherwise, each site had both runners and jumpers.

Table 1: Data Characteristics

Parameter	Mean	Median	Max.	Min.	Std. Dev.
Cycle length (sec.)	79	80	90	50	12.3
Green time (sec.)	17	17	40	6	9.4
Clearance time (sec.)	11.1	10.5	18	8	2.2
Volume entering (15 min.)	127.2	115	445	10	93.1
% complying	74.4	78.2	97.4	33.3	14.6
% runners	9.8	8.7	25.0	0	6.1
% jumpers	15.8	12.2	49.0	0.76	13.0
Average stopped delay (sec.)	18.9	18.4	35.0	6.3	7.1

Locations with high proportions of jumpers tended to be crossings of one way streets with platooned vehicular traffic that was under capacity. The vehicle platoons usually left no gaps for jumpers during the early portions of the pedestrian red. However, when gaps appeared in the vehicular traffic near the end of the platoon's signal phase, jumpers would often begin their crossing before receiving the pedestrian green. One location included 30.6% jumpers around 9:30 a.m. when vehicular traffic was far below capacity and only 4.0% around 5:00 p.m. when vehicular traffic was congested. A second site had 34.8% jumpers when lengthy gaps appeared at the end of a platoons passage but only 4.0% when those lengthy gaps were not present.

The author has observed locations in which entire platoons of 20 to 30 persons left the curb several seconds before receiving the pedestrian green. Since the jumpers only have to watch for traffic coming from one direction, the one-way street crossings might be viewed by them as a relatively safe maneuver.

Results

The volume and signal timing data for each of the 47 crossings was applied in Equation 1 to estimate delay. Equation 1 assumes pedestrians arrive randomly and only cross on a WALK signal. These estimates were then compared to measured delay as shown in Figure 1. A significant correlation (r = 0.690) was found between the results. A perfect model would have all data points fall on a the line (with a slope of one) shown. Instead, most of the predicted delays are greater than the measured delays, with predicted delay averaging 31% larger than those which were measured. This result supports the concept that some pedestrians reduce their own delay by violating the signal indication

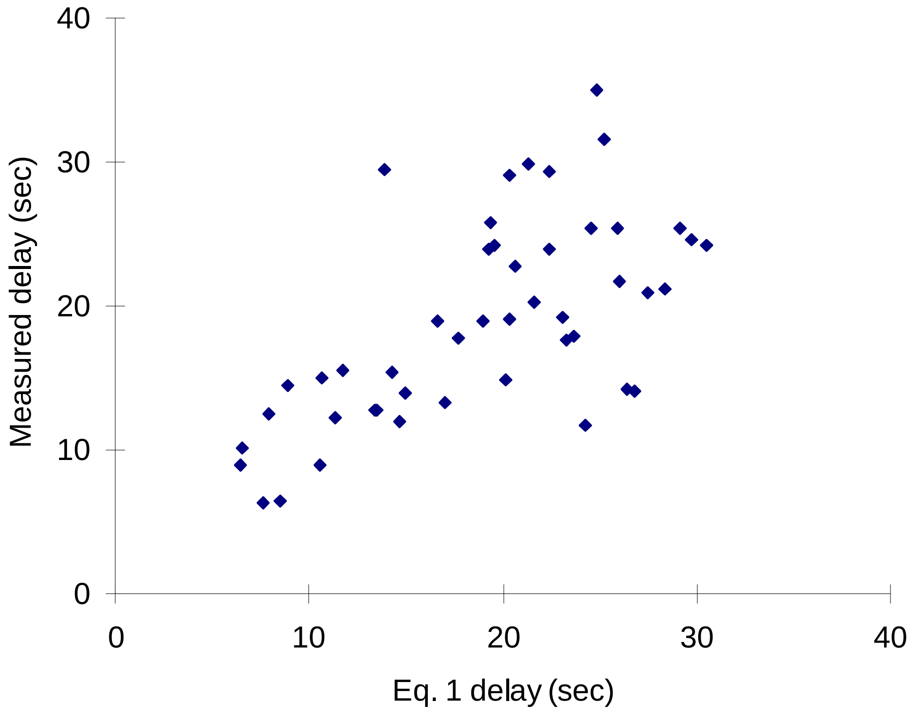

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Figure 1: Measured Delay vs. Equation 1 Delay

Predictions from Equation 2 were also compared to measured delay, as shown in Figure 2. Equation 2 assigns no delay to runners and jumpers. The correlation was weaker ($r = 0.518$) but the average delay prediction was only 3.8% smaller than that measured.

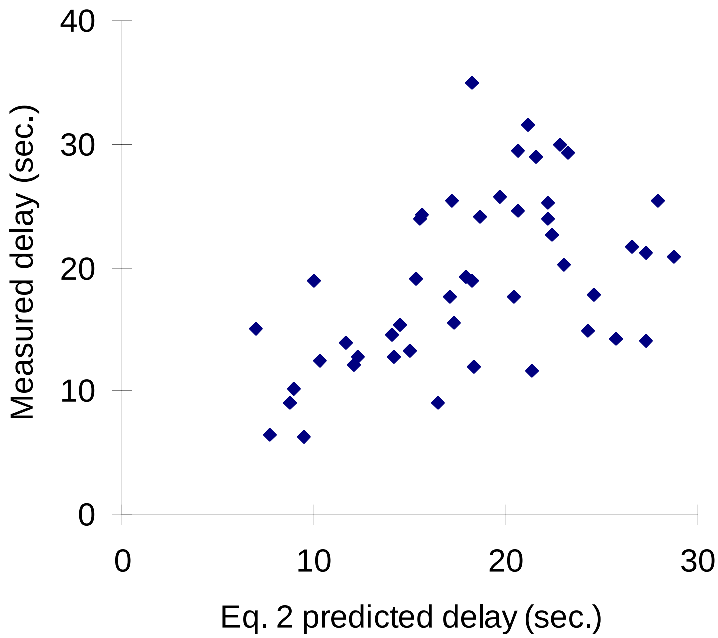

Figure 2: Measured Delay vs. Equation 2 Delay

The data were then examined to estimate the potential delay saved by runners and jumpers. First, Equation 1 was modified by subtracting the estimated delay avoided by runners during each clearance interval (referred to here as Equation 1A). The delay avoided by runners was estimated by determining the time during the clearance period when the last runner entered the intersection. When more than one runner used the clearance interval, the runners were assumed to enter the intersection at a uniform headway between the beginning of the clearance interval and the entry of the last runner. Each runner therefore was assumed to save all of the delay during the red phase and part of the delay during the clearance interval. The resulting values had a correlation with measured delay somewhat less then Equation 1 but gave results which averaged only 0.4% greater than measured delay.

Second, Equation 1B was intended to subtract, from Equation 1, the estimated delay avoided by both runners and jumpers. When there was more than one jumper, the entry of jumpers was assumed to be at uniform headways between the first jumper and the onset of green. This approach underestimated average delay by 6% and had a slightly lower correlation with measured delay than Equation 1A. Table 2 gives these results.

Table 2: Comparison of Measured vs. Predicted Delay

Parameter	Delay from:				
	Measured	Eq. 1	Eq. 2	Eq. 1A	Eq. 1B
Average delay (sec.)	18.9	24.8	18.2	19.0	17.8
Ratio to measured delay	-	1.311	0.962	1.004	0.940
Correlation to measured delay (r)	-	.690	.518	.637	.595
Total delay (person-sec.)	116,640	142,886	108,344	113,146	106,640
Ratio to measured delay	-	1.286	0.975	1.018	0.960
Ratio to Eq. 1 delay	0.777	-	0.758	0.792	0.778

Table 2 also gives results in terms of total person-seconds of delay at all intersections. Total measured delay was 116,640 person-seconds but jumpers and runners avoided some significant additional delay. The 819 jumpers saved about 6500 person-seconds, or about 7.9 seconds each (from Eq. 1A minus Eq. 1B). The 504 runners avoided an additional 29,740 person-seconds or about 59 seconds each (from Eq. 1 minus Eq. 1A).

AN ALTERNATIVE MODEL OF PEDESTRIAN DELAY

Runners saved much more time per person than did jumpers. Runners were also responsible for about 82% of the total delay savings from runners and jumpers combined. An estimate of the number of runners and their delay reductions would appear to be an appropriate modification to Eq. 1.

From the data in Table 1, the typical signal had 14.1% of the cycle time (11.1 seconds of a 79 second cycle) devoted to the clearance interval of the crosswalk. Equation 1 assumes that no pedestrians who arrive during this interval will enter the crosswalk. However, 8.6 % of the pedestrian volume (504 of the 5853 entering pedestrians) were runners.

A potential modification to Equation 1 would be to assume that some portion of the clearance interval will be used for entering the crosswalk. The volume and timing of each signal indicated that, if arrivals were random, 14.2% of pedestrians would have arrived during the clearance intervals. Since 8.6% of pedestrians were runners, it would appear that about 69% of the clearance period was used as if it were effectively green. Thus Equation 1 might be modified by adding part of the clearance time to the WALK time, as shown below.

$$D = \frac{(R + 0.31A)^2}{2C} = \frac{[\,C-(G + 0.69A)\,]^2}{2C} \qquad \text{(Eq. 3)}$$

where: D = average delay per pedestrian
R = duration of red or DON'T WALK signal
A = duration of clearance or flashing DON'T WALK signal
C = cycle length

G = duration of WALK signal

The results from applying Equation 3 to the signal and crossing data are shown in Figure 3. The correlation between measured and predicted delay was 0.680. Average delay was only 1.05% higher than that measured.

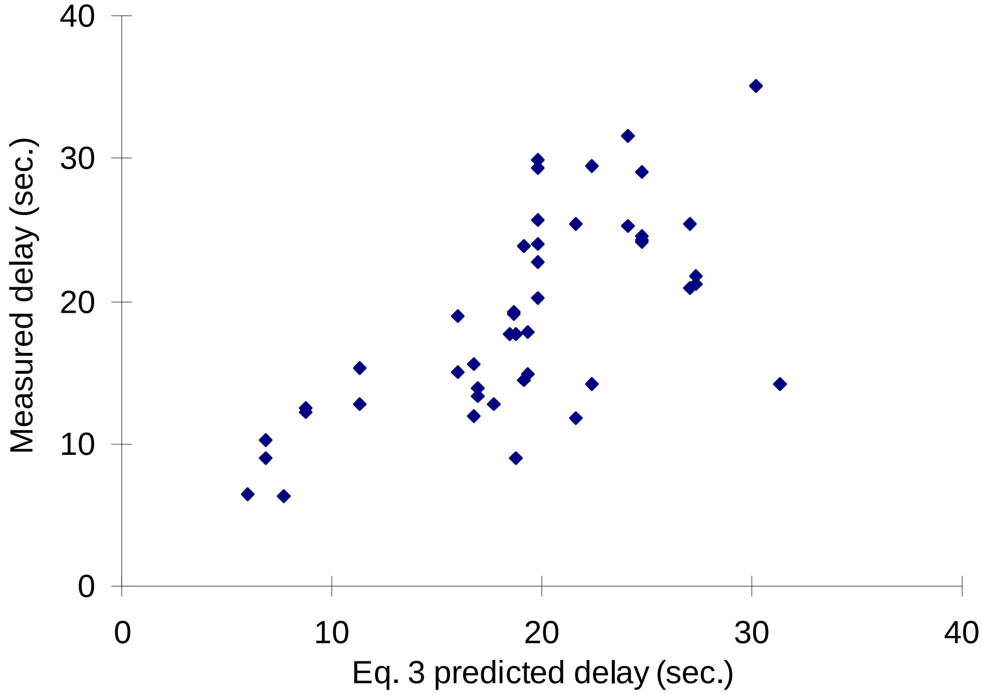

Figure 3: Measured Delay vs. Equation 3 Delay

CONCLUSIONS

In modeling pedestrian delay, pedestrians are usually assumed to follow signal indications. The data indicate that a significant number of pedestrians had small delay savings, averaging 7.9 seconds, by entering the crosswalk before the WALK indication. Another significant category of pedestrians saved an average of 59 seconds each by beginning their crossing during the pedestrian clearance interval.

Equation 1, by assuming crossings only occur during the WALK interval, overestimated delay by about 30%. Equation 2 came much closer to correctly estimating average delay but requires one to estimate the number of pedestrians who will cross without the WALK signal.

Equation 3 was developed here to recognize that significant numbers of pedestrians use the flashing DON'T WALK clearance interval to enter the intersection, thereby avoiding large delays. These delay savings accounted for most of the difference between the average delay of Equation 1 and average measured delay.

Equation 3 might be viewed as implying that pedestrian arrivals throughout the cycle are random and that 69% of the clearance interval is used as if it were effectively pedestrian green time. Another argument might be made. Most pedestrians would hesitate to enter the intersection when half of the clearance interval has expired. However, most are willing to enter during the first few seconds of clearance without feeling rushed. Other pedestrians, who begin further from the intersection when the WALK and flashing DON'T WALK intervals first appear, increase their speed while still on the sidewalk and maintain this higher speed on the crosswalk in order to clear the intersection before a conflicting vehicle movement receives a green signal. This would mean that pedestrian arrivals during the latter parts of the WALK phase and during the clearance interval are not random. Rather, the arrival patterns during this time are biased to allow more pedestrians to enter the intersection early enough in the clearance interval to cross on the current cycle, rather than waiting for the next pedestrian green.

It is clear that pedestrians can save significant amounts of delay by using more than just the WALK interval to enter the intersection. The flashing DON'T WALK interval attracts a significant number of these pedestrians, who thereby reduce their delay by amounts exceeding the pedestrian red time of the signal.

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